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A "test of concept" comparison of aerodynamic and mechanical resuspension mechanisms for particles deposited on field rye grass (*Secale cercele*). Part 1. Relative particle flux rates

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Abstract

Resuspension of uniform latex micro spheres deposited on a single seed pod of field rye grass stalk and head was investigated experimentally in a wind tunnel. The experiment was designed to distinguish aerodynamic (viscous and turbulent) mechanisms from mechanical resuspension resulting from the oscillatory impact of the grass hitting a stationary object. The experiment was run for deposited spherical latex particles with diameters from 2 to 10 μm. Wind tunnel tests were run for wind speeds from 2 to 18.5 m s^{-1} and a turbulence intensity (root-mean-square fluctuation wind speed/mean wind speed) of 0.1. Our experiments showed the following for our test of concept experiment:

- Resuspension particle flux increases when mechanical impacts occur.
- Mechanical resuspension dominated for 2 μm particles over purely aerodynamic resuspension, but for larger particles aerodynamic mechanisms were roughly equally effective in resuspending particles.

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Keywords: Resuspension; Aerosol; Grass; Wind-tunnel; Aerodynamic

1. Introduction

The literature of resuspension may be divided into (1) large-scale studies where individual details of resuspension are lumped together in an empirical approach, and (2) detailed studies in which mechanisms releasing particles at a microscale are examined. Large-scale resuspension research often expresses results in terms of resuspension factors K (air concentration divided by surface concentration—units of length^{-1}) and resuspension rates (flux of contaminant divided by surface concentration—units of time^{-1}). Large-scale studies are usually motivated by large-scale contamination by hazardous substances (for example, radionuclides from the Chernobyl 1982 accident (Cambray, 1989)) and the need to predict the spreading of contamination and the lifetime of hazardous air concentrations. Small-scale resuspension studies include theoretical modeling and experimental studies that are usually motivated by the need to find explanations for resuspension behavior

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rather than for direct large-scale applications. The subject of this report is work on small scale resuspension, specifically resuspension from grass.

1.1. Small-scale aerodynamic resuspension models

Aerodynamic models include consideration of balance of forces and statistical mechanisms. Balance of forces accounts for forces holding the particles to the surfaces versus those forces acting to remove the particles from the surfaces. Experimental studies of particle motions show that particles entrained into a turbulent fluid tend to move vertically into the stream with unsteady motions (Sutherland, 1967). Braaten et al. (1990) and Braaten and Paw U (1992) stressed the importance of bursts of a sweeping eddy having the characteristics of large shear stress near the wall where particles are sparsely deposited, breaking up the viscous sublayer and transporting fluid forces to the particles.

Reeks et al. (1988) proposed a different aerodynamic mechanism that calls for the individual particles to accumulate energy from the turbulent stream (most efficiently at a resonant frequency for the particle). Wu et al. (1992a) presented a model for monodisperse particle resuspension and Wu et al. (1992b) gave results for wind tunnel experiments for aerodynamic resuspension of monodisperse particles. Loosmore and Hunt (2000) showed that a small sustained dust flux can occur from a smoothed dust bed in the absence of sandblasting. Applying their results to resuspension from grass, one could also expect some resuspension from grass by direct aerodynamic entrainment.

The above aerodynamic resuspension models do not allow for contributions by forces liberating particles from the substrate itself. That is, the substrate is assumed to be an unmoving and passive surface. Casual observation of grass in wind, however, shows that not only is grass moving in the wind, but each grass blade often slaps (impacts) or rubs its neighbors with an intensity that depends on the wind. In addition, properties of the grass blade, such as geometric dimensions of the grass blade, stiffness, and moisture content possibly affect impacts of the blade. The importance of the aerodynamic resuspension, including oscillation of vegetative surfaces and flapping of the blades, should be determined relative to blade-to-blade impaction mechanisms.

1.2. Evidence for the importance of mechanical resuspension

The importance of mechanical disturbance is seen by the differences in resuspension factors given by Sehmel (1984) for mechanical activities affecting contaminated soil versus those for wind. Garland (1979) showed a two-orders-of-magnitude increase of the resuspension factor for the mechanical disturbance caused by a full 5-l bottle dragged along the grass 20 times in 5 min in $10\,\mathrm{m\,s^{-1}}$ wind compared to the $10\,\mathrm{m\,s^{-1}}$ wind alone. Other evidence for the importance of mechanical disturbance for resuspension includes:

- Threshold velocities for particles smaller than 10 μm diameter are several times greater than those for 100 μm particles (Bagnold, 1941). Nonetheless, one observes submicrometer to 10 μm particles in wind erosion events for winds greatly below the threshold velocity for the above-mentioned particles.
- Shao et al. (1993) demonstrated the importance of Gillette and Walker's (1977) sandblasting mechanism when they showed that sand-grain bombardments (saltation), rather than aerodynamic entrainment, are the overwhelmingly dominant mechanisms in maintaining fine particle emissions from the surface.
- Alfaro (1997) showed that size distributions of particle emissions smaller than 10 μm could be simulated by sandblasting theory.

1.3. Aerodynamic quantities over and within grass

Micrometeorological measurements over and within grass have been made. Rider and Robinson (1951) and Brutsaert (1982) give measurements that show that the largest wind forces are very near the top of the grass blades. For direct aerodynamic entrainment, mechanical disturbance associated with movement of the grass blades, or strong localized aerodynamic entrainment, the most intense resuspension forces would be in the top 20–30% of the blade height. Measurements of wind shear stress within a canopy of waving wheat by Brunet et al. (1994) showed that "the canopy acts as an efficient sink for momentum: about two-thirds of the momentum is extracted by the plant elements within the top-third of the canopy." Lemon (1965) and Denmead (1976) have shown that wind within canopies is quite different from the usual logarithmic profile above vegetation. The within-canopy profiles give rise to the above momentum distribution.

1.4. The Nicholson experiment

Nicholson's experiment (1993) provides a valuable departure point for wind tunnel studies of resuspension from grass. Four sizes of tagged spheres were deposited onto concrete and grass surfaces. An outdoor wind tunnel was placed over the deposition surfaces, and resuspension rates were calculated versus wind speed. Two conclusions were made: (1) The resuspension rate was higher for the grass surface than for the smooth concrete surface for particles larger than 4.1 μm for wind speeds $4 < U < 7\,\mathrm{m^{-s}}$, except for 22.1 μm particles at a possible threshold velocity of $6\,\mathrm{m\,s^{-1}}$ on the concrete. (2) The rate of increase of the resuspension rate with wind speed U for 9.6 and 17.5 μm particles is proportional to U^x, where x is close to 3.

1.5. Goal of the experimentation

The goal of the experimentation is to answer the following questions:

(1) Does a mechanical disturbance of grass (hereafter abbreviated as "M") increase the resuspension rate of particles deposited on grass when compared to the action of aerodynamic mechanisms (hereafter abbreviated as "A") alone? Examples of A are direct actions of the turbulent air motions: vibrating of vegetative surfaces, production of sweeping eddies that may detach particles, and viscous forces that remove particles at the mean wind speeds. The M considered in this experiment is the striking of the oscillating grass stalk against a stationary object in response to turbulent air motions.
(2) Does particle size affect the particle flux enhancement of the M mechanism?
(3) What are the thresholds of wind speed for A resuspension only?

To answer the above-three questions, we chose one specific grass to serve in a "test-of-concept" experiment for grass in general. Furthermore, we chose one specific method of deposition of particles to the grass, one specific composition and one shape of particle. In short, we chose specific qualities; if the questions could be answered for one narrowly designed experiment, further work of this kind could be of value.

2. Experimental details

2.1. Deposited particles

Particles deposited on the surface of the grass were "uniform latex micro spheres" manufactured by Duke Scientific Corporation.[1]

The means and coefficients of variation (CV) of the latex micro sphere diameters are: 0.99 μm, 2.1%; 2.02 μm, 3.1%; 3.15 μm, 4.4%; 4.5 μm, 20.0%; 8.1 μm, 16.0%; and 9.9 μm, 16.2%. These sizes were determined by the manufacturer. The particles have a density of 1050 kg m^{-3}.

2.2. Grass and deposition of the particles

We chose a grass similar to wheat to be consistent with the Brunet et al. (1994) study. This grass was field rye grass (*Secale cercele*) which was locally available. Each rye grass stem (stalk) had a seed pod at the top. All grass was air dried at least 2 months in a room having constant nominal temperature of 21°C and average relative humidity of about 70%. The diameter of the stalk, the length and diameter of the seed pod are given in Table 1 along with our parameter of stiffness, the force constant k of Hooke's law, $k = F/x$. F is the force imposed on the grass stem supported horizontally at a distance of 0.162 m from the end of the grass support tube (the same distance in our experiments from the top of the grass support tube to the kinetic energy sensor). Here x is the vertical displacement of the stem measured at the point of the imposed force. We used two forces: $m_1 g$ and $m_2 g$ where g is the acceleration of gravity and m_1 and m_2 were 3 and 5.9 g. Although we do not claim that the grass stems obeyed Hooke's law for more than a small displacement of the stem, the mean values of k for the two forces differed by only 6.5% of the mean value of k using both forces.

Table 1
Grass geometric properties and Hooke's force constant measure of the stiffness of the grass stems measured at a distance of 0.162 m of horizontally supported grass stems using two forces

Grass property	Mean	Standard deviation	Number
Stem diameter	0.0013 m	0.0002 m	61
Seed head length	0.065 m	0.018 m	61
Seed head diameter	0.005 m	0.001 m	61
Hooke's law $k = (F/x)$ (J m^{-2})	1.84×10^{-4}	1.45×10^{-4}	91

Because Brunet et al. (1994) found that most of the momentum extraction of wheat grass occurred at the top one-third of the canopy, we applied the particles to the seed pod of the plant. To measure resuspension both with and without the M for the same rye grass stalk, we tested a single stalk of grass in isolation, both with and without the mechanical impacts. The polystyrene latex micro spheres were packaged at 10% solids by weight in deionized water with a trace of surfactant. The deposition of the particles was done as follows: after swirling of the manufacturer's bottle for 2 min to mix, 0.14 g of the suspended particles were removed from the bottle and painted onto the surface of the rye grass seed head with a small brush. Although care was taken to apply all the particles only to the seed head area, some loss of particles was observed in the form of drips. Because of this loss of particles, we did not have confidence in the nominal quantity of particles applied to the grass. Following application of the particles to the grass surfaces, the grass was allowed to dry for 24–48 h at room temperature (21°C and 70% relative humidity). The estimated numbers of particles deposited onto the seed pod, disregarding losses of particles in the

[1] Names of commercial products imply no endorsement by the authors or the US Department of Commerce.

application, are: 3×10^9 for 2 μm micro spheres, 8.2×10^8 for 3.2 μm micro spheres, 2.8×10^8 for 4.5 μm micro spheres, 4.8×10^7 for 8.1 μm micro spheres, and 2.6×10^7 for 9.9 μm micro spheres. It must be emphasized that our method of application of the particles, although controlled and reproducible, is never-the-less different from natural particle deposition from the air. For example, the trace amount of surfactant present in the deionised water could possibly, when dried, bind the particles to the plant surface.

2.3. Detection and quantification of resuspended particle fluxes

Detection and quantification of resuspended particles were accomplished using the Grimm Model 1.105 dust monitor.[1] Air was drawn into the instrument through a nozzle and the instrument classified the particle size based on the amount of light scattered 90° from a beam produced by a laser diode. The signal from this light scattering was collected on a photo diode detector amplified and analyzed by an eight-channel pulse height analyzer. Optics of the sampler were protected by sheath air produced by filtering of the ambient air. The eight-channel size distribution had the following size ranges: 0.5–1.0, 1.0–2.0, 2.0–3.5, 3.5–5.0, 5.0–7.5, 7.5–10, 10–15 μm and larger than 15 μm. Particle sizes were calibrated with polystyrene latex particles. The latex micro spheres (Section 2.1) were chosen so that they could be detected and discriminated by the eight-channel dust monitor. To qualify for the interpretation of particle resuspension in our data, the particle had to be in the correct size range and in concentrations greater than the background (blank) as measured before the resuspension tests. In practice, several blank concentration runs were made during the resuspension tests. The wind speeds for the blanks ranged from 0 to $1.7\,\mathrm{m\,s^{-1}}$. For some of the blank runs, grass having no micro spheres applied to its surface were run in the tunnel. Grass having no micro spheres did not produce a higher blank compared to blanks produced with no grass in the tunnel. Average concentrations of several background runs were subtracted from the concentrations detected for each resuspension run. Data was discarded for which the ratio of blank concentration to sampled concentration exceeded 0.1.

2.4. Wind tunnel

To produce wind having known turbulence characteristics, we used the Fluid Modeling Facility calibration wind tunnel. It is a suction-type tunnel with a cross section of 1 m × 1 m. The nominal range of centerline wind speed is 0 to $20\,\mathrm{m\,s^{-1}}$. Turbulence was artificially induced at the front of the working section by using a rectangular grid. The grid was made of flat aluminum strips which were 0.0127 m wide. The openings of the grid had a dimension 0.05 m × 0.05 m. The grid-induced turbulent structure in the present wind tunnel was most recently measured by T. Reinhold (unpublished manuscript, Fluid Modeling Facility). Reinhold's measurements, as well as previous measurements of grid turbulence in this tunnel, showed that the turbulent intensity (root-mean-square fluctuation of wind speed/mean speed) distribution downwind of a grid is Reynolds' number (i.e., wind speed) independent. This is consistent with the conventional understanding of grid turbulence as originally described by Batchelor and Townsend (1948). The turbulent intensity is equal to 0.1 at a distance 1.09 m downwind of the grid where the apparatus for these experiments was located. The speed of the wind at the tunnel midpoint was recorded from the tunnel fan tachometer which was calibrated by a Pitot tube. A photograph of the wind tunnel is given in Fig. 1.

The instruments were placed in the wind tunnel as shown in Fig. 2. The rye grass was held by a stand containing a small-diameter tube mounted vertically on a weighted stand; the top of the tube was 0.288 m above the floor. The stem of the rye grass was cut so that the seed pod (driven by turbulent wind fluctuations) would impact a kinetic-energy-measuring cylinder at the end of its farthest downwind oscillation at a height of 0.45 m above the floor and 1.09 m downwind of the grid. A second kinetic energy sensor, never impacted by the grass was set within 0.5 m of the primary sensor within the wind tunnel so that sensor response to vibration, noise and wind ("background") could be removed from the sensor being impacted by the grass seed pod.

In an effort to concentrate resuspended particles from the entire surface of the seed pod, a 19° cone having a frontal opening of 0.125 m in diameter was mounted with its center 0.02 m behind the kinetic energy

Fig. 1. Photograph of the wind tunnel used for the resuspension experiment.

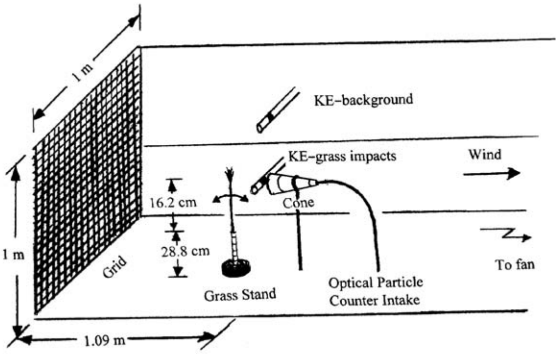

Fig. 2. Schematic drawing of the suction-type wind tunnel used for the resuspension experiment. At the front of the test section is a turbulence-producing grid that causes the turbulent intensity to be equal to 0.1 at the location of the rye grass. The rye grass is held by a stand containing a vertically pointing small-diameter tube. The kinetic energy sensor is situated so that the top part of the grass impacts it at the end of its farthest downwind oscillation. A second kinetic energy sensor is situated so that the grass never impacts it, but responses to vibration and noise of the wind tunnel may be measured and removed from the instrument response of the sensor being impacted by the oscillating grass. The intake for optical particle counter is set at the downstream opening of a 19° cone that is placed to concentrate the resuspended particles at the sampling point.

instrument; the downwind cone-opening was 0.03 m in diameter and was located 0.30 m downwind of the kinetic energy instrument. The nozzle of the optical particle counter (OPC) intake was mounted at the center of the downwind opening of the cone. The nozzle used was designed to sample isokinetically for wind speeds of 16–25 m s^{-1}. Since the wind speeds at the OPC intake are nominally increased by a factor of 17.4 by our cone sampler and our minimum wind tunnel speed was 2 m s^{-1}, the intake did not sample isokinetically since we did not possess smaller intake nozzles. Collection efficiencies for such sampling would be expected to increase with wind speeds which are all higher than the speed of air in the sampling tube (Fuchs, 1964). However, collection efficiencies for the same sized particle for the same wind speed of the tunnel are the same, so that comparisons can be made for relative differences of our A and (A + M) resuspension particle samples for the same particle size and wind speed.

2.5. Protocol of wind tunnel testing

At the beginning of all tests the grass support stand was moved so that the seed pod would just touch the Sensit sensing surface. The support was then moved so that the grass stalk would be 0.05 m upwind of the sensing surface in the direction of the turbulence producing grid. At this distance, measurements and visual observations during the experiments showed that the oscillating seed pod would not touch the surface of the kinetic energy measuring device for the strongest wind used (18.5 m s^{-1}). For each resuspension test using a single grass stalk, we first sampled for particle flux for A and (A + M) resuspension at a given wind speed, and then followed with a test for (A + M) resuspension at nominal speed of 18.5 m s^{-1}. Each resuspension test started with a rye grass that had dried for 24–48 h following application of one size of uniform latex micro spheres on the seed pod of the grass (see Sections 2.1 and 2.2). For each test, the following succession of three resuspension runs was used with the same stalk of grass:

(1) A only: at a speed chosen successively from the six possible speeds used in the wind tunnel: 2, 3, 6.1, 9.3, 12.4, and 18.5 m s^{-1}, the grass was subjected to aerodynamic mechanisms of resuspension only. That is, the grass was placed 0.05 m upwind of the kinetic energy sensing device, where it never impacted the kinetic energy measuring device during its oscillation in the turbulent wind. The total running time was one to two minutes.
(2) (A + M): at the same speed as for (1), the grass support stand was moved forward so that the grass would impact the kinetic energy device at every oscillation. This was also run for 1–2 min.
(3) (A + M), high speed: the grass support stand was moved upwind again, so that the grass would not become "trapped" against the kinetic energy sensing device for a wind tunnel centerline speed of 18.5 m s^{-1}. The wind tunnel was now run for several minutes at this top speed with both aerodynamic and mechanical resuspension mechanisms operating. It should be noted that each stalk of grass had a slightly different stem diameter and stiffness.

During the duration of the experimentation, the following measurements were recorded every 6 s on the hard drive of a personal computer: (1) wind tunnel tachometer reading from which wind tunnel centerline speed would be calculated, (2) particle concentration data for eight size ranges of particles measured by the optical particle counter, and (3) kinetic energy output (to be addressed in part 2).

3. Results

3.1. Size distributions of resuspended micro spheres and comparisons with background particle concentrations

The comparisons for the background (or blank—see Section 2.3) and the background plus resuspended particles for the nominal polystyrene latex micro sphere

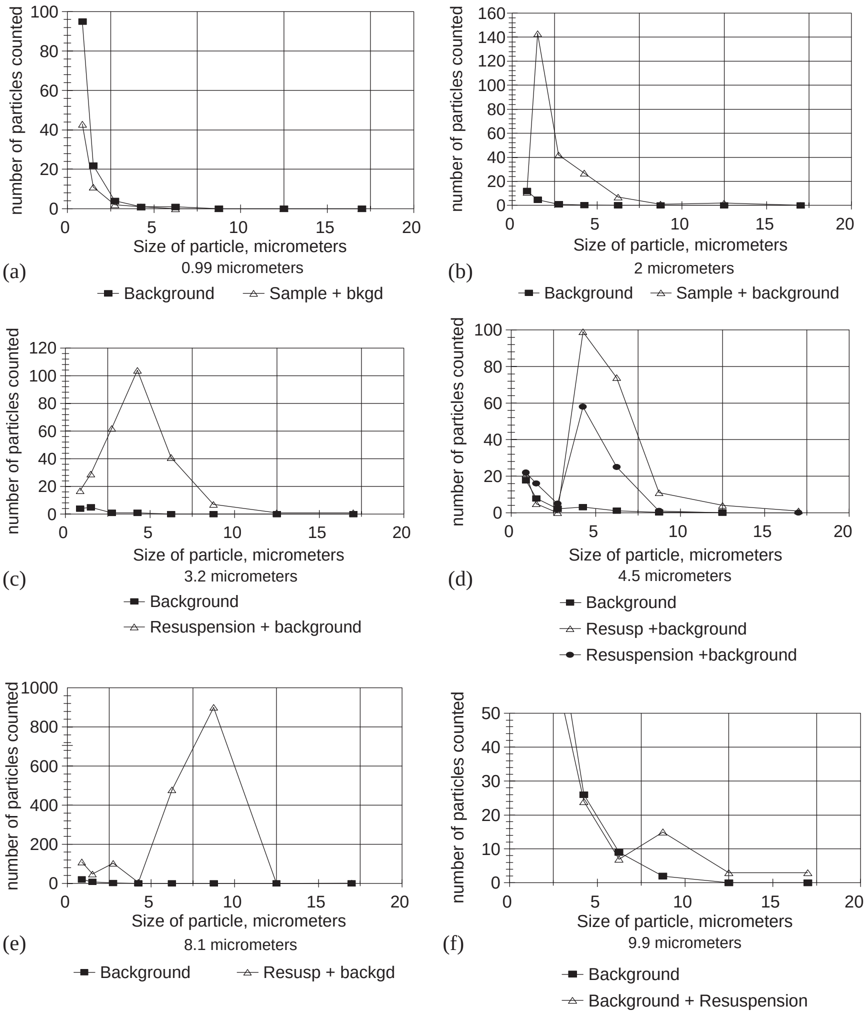

Fig. 3. Particle size distributions for the resuspended uniform latex micro spheres as determined from the Grimm Particle Analyzer. Wind tunnel speed for the size distributions was near the top speed, from 16 to18.5 m s^{-1}. The sizes of the uniform latex micro spheres are: (a) 0.99 μm, (b) 2.0 μm, (c) 3.2 μm, (d) 4.5 μm, (e) 8.1 μm, and (f) 9.9 μm.

diameters 0.99, 2, 3.2, 4.5, 8.1, and 9.9 μm are shown in Figs. 3a, b, c, d, e, and f, respectively. The difference between background and background plus resuspended particles was not distinguishable for the 0.99 μm micro spheres. For this reason, resuspension tests were discontinued for the 0.99 μm particles. For 9.9 μm micro spheres, the increase of particle concentration was apparent for the particle size range including these particles, especially considering the rather wide coefficient of variation for diameter (see Section 2.1) compared to the smaller micro spheres. However, for this test, the enrichment factor (ratio of the 9.9 μm particles in the background plus resuspended to number of 9.9 μm particles for the background alone) was less than a factor of 10 and we discontinued this sized particle. For the other particles tested (2, 3.2, 4.5, and 8.1 μm), however, the enrichment ratio was more than a factor of 10. For these particles, the rather narrow size distribution as well as the large enrichment ratio indicated that we were seeing resuspension of the micro spheres that we applied to the grass stalks.

3.2. *The effect of mechanical impacts of grass and particle size on resuspension of 2 μm micro spheres*

Results for the 2 μm micro sphere tests are shown in Figs. 4a–f. The figures illustrate the data from which we estimated (1) threshold wind tunnel velocity for resuspension by A mechanisms, (2) the ratio of the emission of A to (A + M) particle fluxes, (3) the decrease of resuspension emission with time, (4) the variability of the data caused by the experimental method, and (5)

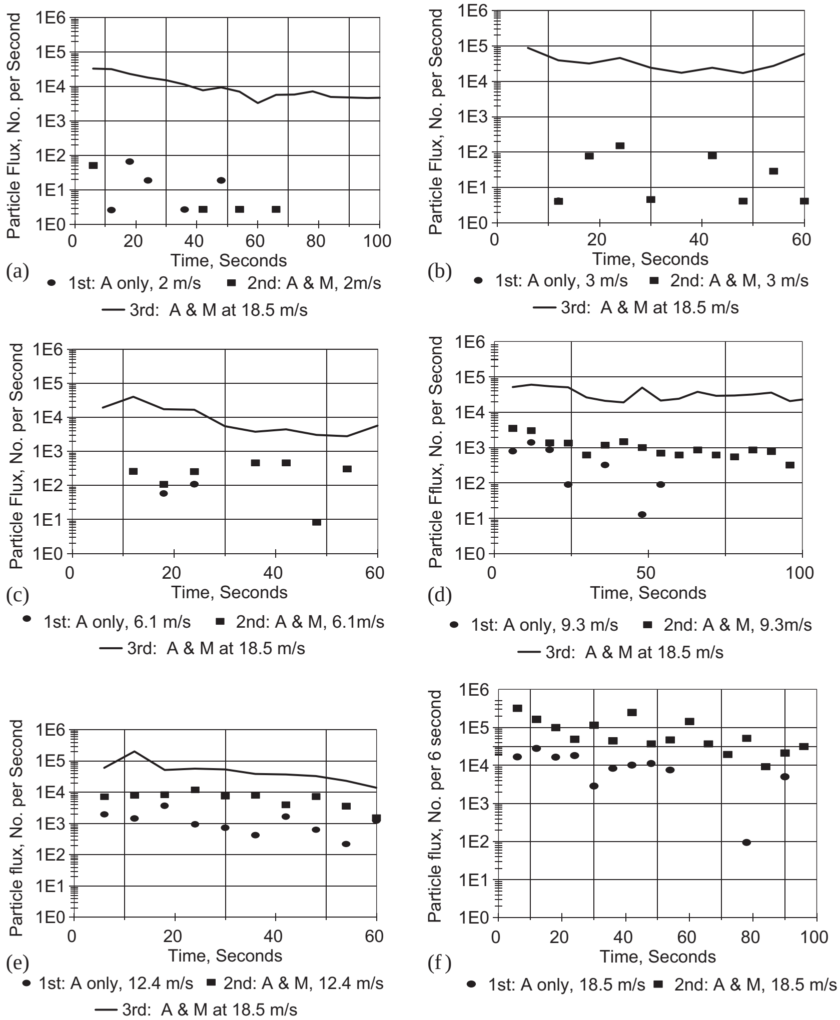

Fig. 4. Total number of 2 μm micro spheres resuspended s^{-1} from the grass at indicated wind tunnel speed for A (aerodynamic mechanisms including eddy sweep, vibration of the grass, or other viscous fluid mechanism), and for (M (the mechanical mechanism) + A) for the following mean wind tunnel air speeds: (a) $2\,m\,s^{-1}$, (b) $3\,m\,s^{-1}$, (c) $6.1\,m\,s^{-1}$, (d) $9.3\,m\,s^{-1}$, (e) $12.4\,m\,s^{-1}$, and (f) $18.5\,m\,s^{-1}$.

threshold kinetic input rate for resuspension by M mechanisms (see part 2, Gillette et al., 2004).

3.2.1. Threshold wind tunnel velocity for resuspension by A mechanisms

The Figs. 4a–f show that there is not a sustained flux of 2 μm particles for wind tunnel winds less than $12.4\,m\,s^{-1}$. However, at $12.4\,m\,s^{-1}$ there is a sustained flux for aerodynamic resuspension. Below wind speeds of $12.4\,m\,s^{-1}$, particles are seen coming off the grass for a limited period of time. We interpret this as a small fraction of the particles being loosely adhering to the grass that are depleted soon following the start of the test. We used the A threshold of $12.4\,m\,s^{-1}$ based on our data. Likewise the threshold for the A mechanisms for the other particle sizes is given in Table 2. The figures show that particle concentrations are higher when the M mechanism is operating than for A mechanisms alone.

3.2.2. Ratio of the emission of A to (A+M) particle fluxes

Because our measured ratios for particle A fluxes to (A + M) fluxes are valid for each particle size and wind speed despite nonisokinetic sampling, the ratios can be averaged for each particle size for all sampled wind speeds above threshold. These averaged ratios are given in Table 2. Whereas the resuspension of 2 μm micro spheres was dominated by mechanical resuspension, viscous/turbulent resuspension is almost equally effective for 3.2 and 4.5 μm micro spheres. However, this

Table 2
Threshold centerline tunnel speed vs. particle size and ratio of resuspension fluxes for A to (A + M)

Diam (μm)	2	3.2	4.5	8.1
Threshold ($m\,s^{-1}$)	12.4	13.5	13.5	16.7
Ratio of Fluxes				
A to (A + M) (%)	15	44	43	47

effectiveness is probably overestimated because the tests for (A + M) resuspension were always done following tests of A resuspension; that is, mechanical resuspension always operated on an already depleted particle source. For 8.1 μm micro spheres, Table 2 shows that the thresholds for A resuspension were at the upper part of the range of our wind tunnel speeds; the A and M resuspension mechanisms were not fully developed at our highest wind tunnel speeds compared to the 2, 3.2, and 4.5 μm micro spheres.

3.2.3. Decrease of resuspension emission with time

The particle emission data suggest an exponential decrease with time. We fitted an equation of the logarithm of the flux rate versus time to all the data for 2 μm. The average time constant (time needed to decrease the flux rate to e^{-1} of the starting rate) was 77 s for all the data. The mean of the standard error of the regressions was 17%. The standard deviation of the individual time constants obtained by regression was 35 s.

3.2.4. Experimental variability

Our measurements for (A + M) resuspension at the nominal wind tunnel speed of $18.5\,m\,s^{-1}$ (the final measurement of every run) are shown in Figs. 4a–f. for the 2 μm micro spheres, These results illustrate the relative variability for (A + M) resuspension for the same particle size and same wind tunnel velocity for experiments that we attempted to make very similar. Resuspension variability is probably caused by slight differences in (1) placement of the grass relative to the fixed impaction object, (2) grass strength and stalk diameters, and (3) deposition of the particles onto the grass.

4. Discussion and conclusions

By dividing the micro sphere particle flux values (number per second) of Fig. 4 by the nominal number of particles deposited on the seed pod (Section 2.2), one obtains an (A + M) resuspension rate of about $10^{-5}\,s^{-1}$ for 2 μm micro spheres for a nominal wind tunnel speed of $18.5\,m\,s^{-1}$. Likewise, the (A + M) resuspension rate for a wind tunnel speed of $18.5\,m\,s^{-1}$ for 4.5 μm micro spheres is about $10^{-4}\,s^{-1}$. Nicholson's initial resuspension rate for 4.1 μm particles for his highest wind tunnel speed of $8\,m\,s^{-1}$ was about $10^{-4}\,s^{-1}$. This agreement must be regarded as only circumstantial, however, since our number of deposited micro spheres is uncertain, and the efficiency of collection was probably greater than 100%. Two differences of our experiment with Nicholson's were (1) we used a higher wind speed and (2) our deposit had been depleted (by A resuspension only) several minutes before beginning the test. Nicholson's resuspension rates typically decreased by 4–5 orders-of-magnitude within 5000 s of run time. Assuming an exponential decay in the rate of flux for Nicholson's experiment, we calculated that his time constant would be approximately 540 s, about 7 times longer than our time constant of 77 s. Since our experiment was of grass directly impacting an immovable object (the KE sensor), it is expected that the effectiveness our resuspension would be greater than that for Nicholson's experiment.

Our experiments suggested the following:

- Resuspension increases with mechanical impacts.
- Mechanical resuspension dominated our 2 μm resuspension, but for larger particles aerodynamic mechanisms were roughly equally effective in resuspending particles.

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